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NOTICES

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14. ABSTRACT

The US Army Tank Automotive Research, Development and Engineering Center's Applied Robotics for Installations and Base Operations (ARIBO) program at Fort Bragg, North Carolina, provided one of the first US-based living laboratories that allowed Soldiers the opportunity to directly interact with a driverless, robotic transport vehicle. Passengers and potential future passengers from the Warrior Transition Battalion (WTB) and Womack Area Medical Center were given the opportunity to provide user feedback during Phase 1 (driver operated) and Phase 2 (safety operator) of development of the vehicle. A total of 26 people including safety operators, passengers, bystanders, and Soldiers from the WTB provided feedback related to trust and acceptability of the vehicle autonomy, as well as design recommendations for increasing future passenger and pedestrian comfort and trust in the driverless transport vehicle. Overall findings suggest that even minimal exposure to robotic systems can increase positive ratings of trustworthiness and acceptability of the future autonomous capabilities of a driverless transport vehicle. However, the vehicle could benefit from a number of design features and capabilities to better communicate its decision-making processes and intent to passengers, pedestrians, and other road users.

15. SUBJECT TERMS

ARIBO, driverless vehicle, human–agent teaming, trust, user perceptions

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1. Summary

This report provides user and potential user preferences and feedback associated with the design and engineering of a US Army driverless vehicle operating through the Warrior Transition Battalion (WTB) medical complex at Fort Bragg, North Carolina. Findings are derived from questionnaires addressing preferences related to perceived trustworthiness and capability of the autonomous system and can be used to inform design of future vehicle attributes and future research. The development and integration of this driverless vehicle was part of the US Army Tank Automotive Research, Development and Engineering Center (TARDEC) Applied Robotics for Installations and Base Operations (ARIBO) program. It provided door-to-door transportation services between the WTB medical barracks and multiple drop-off locations at Womack Army Medical Center. Passengers, potential future passengers from WTB, and bystanders observing the ARIBO vehicle were given multiple opportunities to provide feedback during 2 phases of vehicle development: driver-operated (Phase 1) and safety-operator enabled (Phase 2). Overall findings were very positive toward preferences in the ARIBO driverless vehicle. This suggests that even minimal exposure to robotic systems can increase positive ratings of trustworthiness and acceptability of the future autonomous capabilities. A number of recommendations were on design features and capabilities to better improve decision-making and communicate intent to passengers, pedestrians, and other road users.

2. Introduction: Applied Robotics for Installations and Base Operations

The US Army TARDEC ARIBO program was designed as a series of pilot projects to coordinate technology development with on-base operational needs and applications to accelerate the adoption of autonomous vehicle technologies. In these pilots, users and nonusers had the opportunity to continuously interact with the technologies in a real-world, dynamic setting. The primary advantage of using operational military installations is access to semi-controlled and well-defined, bounded traffic environments combined with the flexibility to modify various elements of the physical infrastructure via the base's chain of command (Straub 2015).

Direct feedback on new technologies can be a challenge for the Army. Small Soldier groups are typically selected and asked to provide feedback on prototype technologies at research and development centers or carefully controlled field exercises in the case of products nearing production readiness. The ARIBO program afforded researchers the opportunity to collect direct feedback from a randomized subset of users from within a specific geographic environment. In this manner researchers could evaluate feedback on technologies with more generalized relevance while still addressing warfighting-related issues such as communications, human–machine interaction, trust, and functional reliability, to name a few.

The Fort Bragg, North Carolina, ARIBO pilot project addressed the issue of autonomous personnel transit. This project was designed to provide on-demand transportation to wounded Soldiers traveling between the WTB barracks and the Womack Army Medical Center (WAMC). Although the program was designed for wounded Soldiers seeking medical treatment, the services were also available to Soldiers and civilians in the medical complex. These frequent, short-distance door-to-door trips* between the medical barracks and appointments at the medical center (Figs. 1 and 2) provided an environment to better understand the systemic impacts of driverless vehicle integration.

* The distances along the designated routes between the WTB barracks and WAMC are between about 1/3 and 3/4 mile. They negotiate mixed-use pedestrian sidewalks, cross a 4-lane divided road around WAMC, and negotiate congested parking lots and traffic circles at the WAMC entrances.

Fig. 1 ARIBO advertisement at Fort Bragg identifying vehicle pickup and drop-off locations

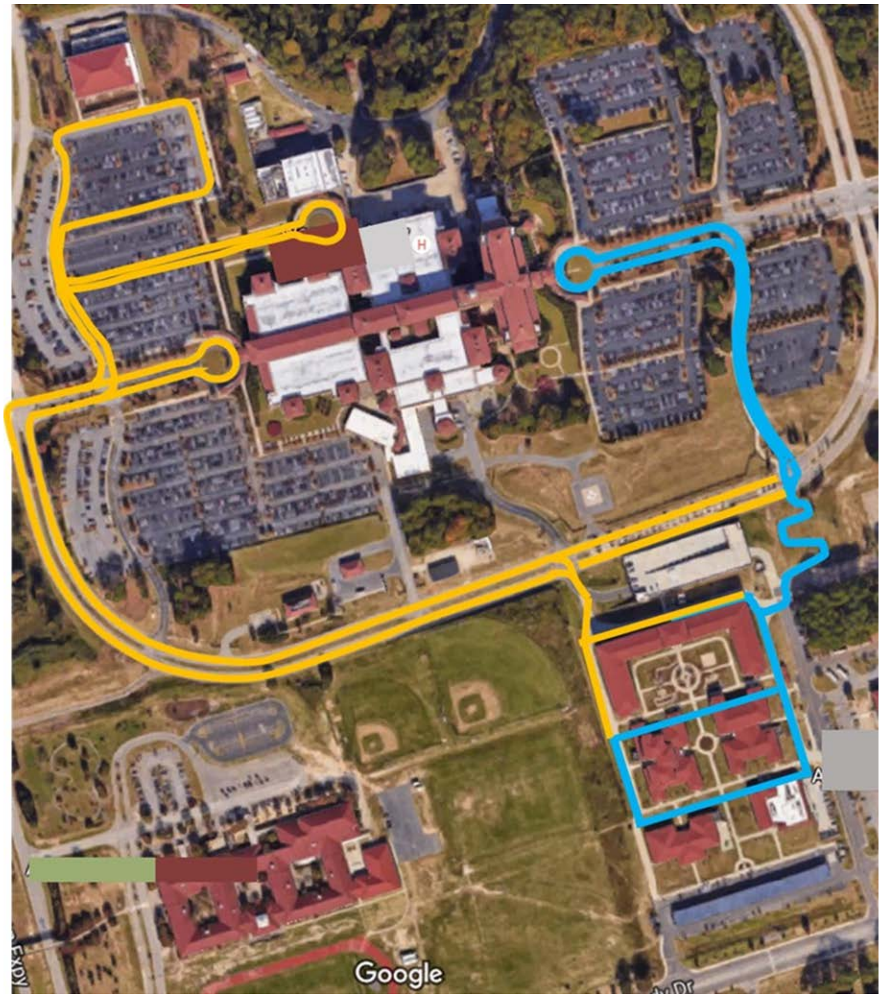

Fig. 2 Planned vehicle routes between WTB and WAMC

Research efforts included comparative analysis between human decisions and autonomy, operational efficiency impact, user and nonuser behavior, trust, and acceptance, as well as vehicle platform and technology development, engineering, maintenance, and reliability assessments. Functionally, the service provided a convenient mode of transportation and an opportunity to increase on-time appointment rates for Soldiers.*

A phased introduction of autonomous control was implemented to ensure safe operations and a smooth increase in trust and confidence of the system. Phase 1 consisted of a human driver-operated shuttle service. During this phase, vehicle data were collected for testing the underlying architecture and autonomy algorithms while a human driver controlled the vehicle. The purpose of this phase of development was 2-fold: first, because the vehicle was operated by a trained human

* Missed appointments account annually for about $1.2 million in opportunity cost.

driver, we were able to evaluate the performance of the sensing and control systems in real-world conditions without increasing risk to any passengers; and second, we were able to evaluate the autonomy's performance not only against real-world conditions, but compare performance and decision-making against the human-driven baseline using a recording scheme and automated analysis based on researcher-defined upper and lower limits of acceptable performance. Results of the analysis provided data for the decision to proceed to the next phase of the project. Phase 2 transitioned the role of the driver to that of a safety operator. A safety operator is trained in manual operations as well as the ability to transition between autonomous control mode and manual control mode. The safety operator sits in the driver's seat, monitoring the status of the vehicle and the environment. The role of the safety operator was to only intervene with the vehicle's autonomy in case of an emergency or potential vehicle error.

2.1 ARIBO Vehicle

The vehicles stationed at Fort Bragg were Cushman Shuttle 6 low-speed electric vehicles (Fig. 3). These vehicles were capable of being optionally manned, meaning they could run either in fully autonomous, driverless mode or in manual, human-operated mode. Operations in human mode were no different from the normal operations of a Cushman Shuttle 6 one might encounter in any similar environment.

Fig. 3 ARIBO driverless vehicle variants: a) 6-passenger and b) Americans with Disabilities Act (ADA)-compliant wheelchair accessible models

The autonomy package included a number of sensors to maintain situation awareness of the environment and operate within the dynamic nature of the medical complex (Fig. 4). Two Velodyne VLP-16 lidars mounted on the passenger-side front and driver-side rear provided a 360° horizontal and vertical field of view with 16 line scans. These are the primary sensors used to detect objects around the vehicle and localize against curbs and other known landmarks. Two Hokuyo single-line lidar sensors were mounted to the front of the vehicle, one pointing forward and one pointing down. The forward-facing Hokuyo served as a redundant obstacle detection sensor. The downward-facing sensor was used for identifying cross-track localization error by detecting lane markings and curbs. Two differential GPS antennas (one on the front center and the other on the rear center of the roof) provided redundant heading measurements and precision localization for the vehicle. Data radio antennas are used to communicate to the control station at the duty desk and with the reservation system. Automotive-grade radar sensors were added to the front sides of the vehicle to provide highly reliable detection of vehicle cross traffic at intersections.

Fig. 4 Vehicle sensors

Cameras were positioned in the cab of the vehicle facing forward (Fig. 5a) and toward the passengers (Fig. 5b). The cameras were for passenger safety and to record the environment. Video data were recorded to Secure Digital cards on the cameras and to an on-board computer. The video was downloaded daily to a secured, encrypted computer accessible only to the researchers.

Fig. 5 a) Forward-facing and b) passenger-facing cameras

Five emergency stop (e-stop) buttons were available that disengage the autonomy system, bring the vehicle to a full stop, and engage the parking brake (Fig. 6). If activated at top speed (15 mph), the e-stop halted the vehicle in about 5.5 m. While in human-mode, the e-stop system was disengaged to eliminate the risk of it being engaged while a person is driving the shuttle.

Fig. 6 Placement of e-stop buttons

2.2 Current Work

The research objective of the work described in this report was to collect user perception data associated with the perceived functionality and trustworthiness of the driverless vehicle during the first 2 phases of operation. Questionnaire data were anonymously collected from individuals (Soldiers and civilians) who may have been a passenger on or observed the ARIBO vehicles operating throughout the WTB medical complex. The purpose of this study was to expand on results from previous simulation experiments involving trust with the ARIBO driverless vehicles to more directly inform future autonomous vehicle and user interface designs required for effective human–robot teaming.

3. Background: Development of the Questionnaire

The questionnaire items were built on previous research efforts to understand the relationship between trust, use, and robot design. As trust is essential for the successful function of any team (Groom and Nass 2007), the use of a robot is directly related to the human's ability to place trust in that robot (Lussier et al. 2007). Hancock et al. (2011) identified through meta-analytic procedures that the primary moderator of human–robot trust development is the perception of the functional capabilities of the robot. However, the perceptions of the functional capabilities of the robot are not exhibited through actual behaviors alone. Duffy (2003) suggested the importance of the physical form of the robot, since it is the compatibility of the design with the functional capability that increases acceptance of the robot. Further, Schaefer and colleagues (2012) found that individuals begin to make perceptions about the potential functionality of the robot (e.g., perceived level of automation and perceived robot intelligence), future outcomes with the robot (e.g., future use), and trustworthiness based on physical form, even depicted through a static image. Perceived intelligence, perceived level of automation, and intended future use were also highly correlated with trustworthiness ratings (Schaefer 2013). Therefore items specific to vehicle intelligence, control, use, safety, and trustworthiness as well as perceptions regarding specific driverless vehicle behaviors (e.g., navigation, obstacle detection and avoidance, and ability to follow road rules) were included in the development of the questionnaire.

This questionnaire was also designed to provide recommendations specific to the design of this driverless vehicle that could potentially increase user comfort or engender trust in the vehicle. These items were based around previous research efforts and developed to benefit future research efforts specific to passengers and bystanders (Straub and Schaefer 2015). In an earlier simulation-based study, the respondents responded to open-ended questions specific to the vehicle design recommendations. These resulted in 4 main areas of missing feedback from the vehicle: navigation-related feedback, proximity-related information, system state, and passenger safety (see Appendix A for further details). The primary sentiment of this prior research was that better shared situation awareness (i.e., the capability that the vehicle is aware of the physical environment and intends to respond appropriately) will engender trust and increase comfort in the vehicle (see Schaefer and Straub 2016).

4. Methodology

Data were collected using a questionnaire. The questionnaire was available to both passengers and bystanders, also referred to as observers. A passenger was someone who received a ride from one point to another with no responsibility for the safety of others or the safe operation of the vehicle, whereas a bystander was someone who simply witnessed the vehicle in operational mode. Respondents included both Soldiers and civilians who previously scheduled a ride or those who were recruited by email from the battalion command. Respondents with scheduled rides automatically received an electronic version of the questionnaire following their ride. Others had the opportunity to complete either the electronic version via a web link on their own time or the paper version in person immediately following the ride.

4.1 Questionnaire

A 16-item author-created questionnaire was accessible via paper and pencil, as well as through SurveyMonkey.com, an online questionnaire software program that can be accessed from computer or smart phone. Appendix B includes 2 versions of the questionnaire for each phase of operation. Phase 1 items were worded in the future tense since a driver was operating the vehicle, while Phase 2 items were worded in the present tense since the vehicle was operating autonomously.

The first 4 items were designed to gather information about the respondent's interaction with the vehicle, number of times as a passenger, first time filling out questionnaire, and if they had seen the vehicle operate autonomously (even if they never rode on the vehicle). Items 5–9 were 7-point Likert-type scale items related to questions used in previous work to identify perceptions about the trustworthiness of specific robots (Schaefer et al. 2012; Schaefer 2013). Items 10–13 were specific to the acceptability of the autonomy-enabled capabilities of the vehicle. The final open-ended questions were included to help direct future research. They included items that built on previous simulation research to identify specific design elements that could be used to increase comfort or engender trust while riding in the vehicle (Schaefer and Straub 2016), and increase comfort or engender trust for pedestrians (Straub and Schaefer 2015). No personally identifiable information was collected during this study.

4.2 SurveyMonkey.com

Following all scheduled rides, respondents received an automatically generated email or were handed a flyer with the opportunity to complete the questionnaire via SurveyMonkey.com. SurveyMonkey.com was selected because it has been approved for use by the US Army Research Laboratory's Information Assurance Management Office. Backup paper and pencil versions of the questionnaire were also available. If a paper and pencil version was completed, then data were entered into the SurveyMonkey.com web link so that all of the data were complied.

4.3 Respondents

Respondents consisted of Soldiers and civilian personnel who 1) had scheduled transportation using the ARIBO driverless vehicle, 2) had observed the vehicle operating throughout the WTB medical complex, or 3) were members of the WTB that may or may not have seen the vehicle operating autonomously throughout the medical complex. A total of 26 responses were recorded. These included 7 responses during Phase 1 (July–Oct 2016) during which the vehicle was driven by a human operator and 19 responses during Phase 2 (Nov 2016–Aug 2017) when the human driver relinquished driving control to the vehicle and assumed the role safety operator.

5. Results and Discussion

The user preference questionnaires were completed by the driver or safety operator of the vehicle (N = 3), passengers (N = 16), bystanders or observers (N = 6), and 1 Soldier in the WTB who did not report being a passenger or bystander. More specifically, out of the 26 responses, 7 people never rode the vehicle; 10 people had between 1 and 4 rides on the vehicle; 3 people rode the vehicle between 5 and 10 times; and 6 people rode the vehicle more than 10 times (see Fig. 7). All 26 respondents saw the vehicle operating in the area surrounding the WTB Medical Complex, but only 15 reported seeing the vehicle operate autonomously (2 from Phase 1 and 13 from Phase 2). The remainder of this section describes perceptions of trustworthiness, perceptions of autonomous vehicle capabilities, and recommendations for design guidelines to increase comfort and trust of both riders and pedestrians.

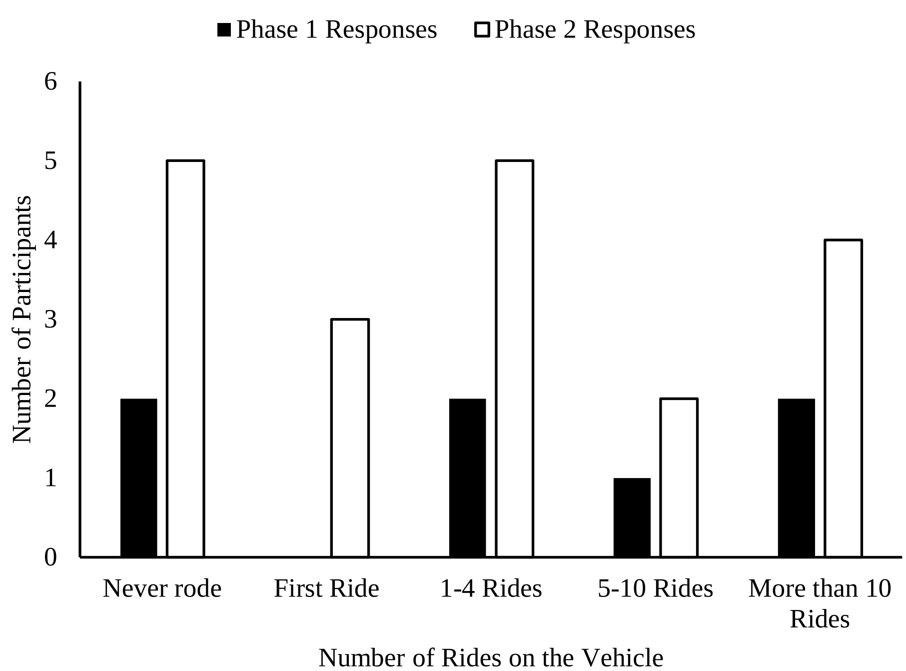

Fig. 7 Self-reported ridership numbers for Phase 1 and Phase 2 of vehicle operation

5.1 Trustworthiness

The questions to assess user perceptions of trustworthiness included ratings of perceived levels of vehicle intelligence, autonomy (i.e., the vehicle's ability to control itself), trustworthiness, level of use, and safety. Twenty-four out of 26 respondents answered these questions. Overall, results demonstrated positive agreement in support of perceived intelligence, perceived level of autonomy, and perceived trustworthiness of the ARIBO vehicle (Fig. 8).

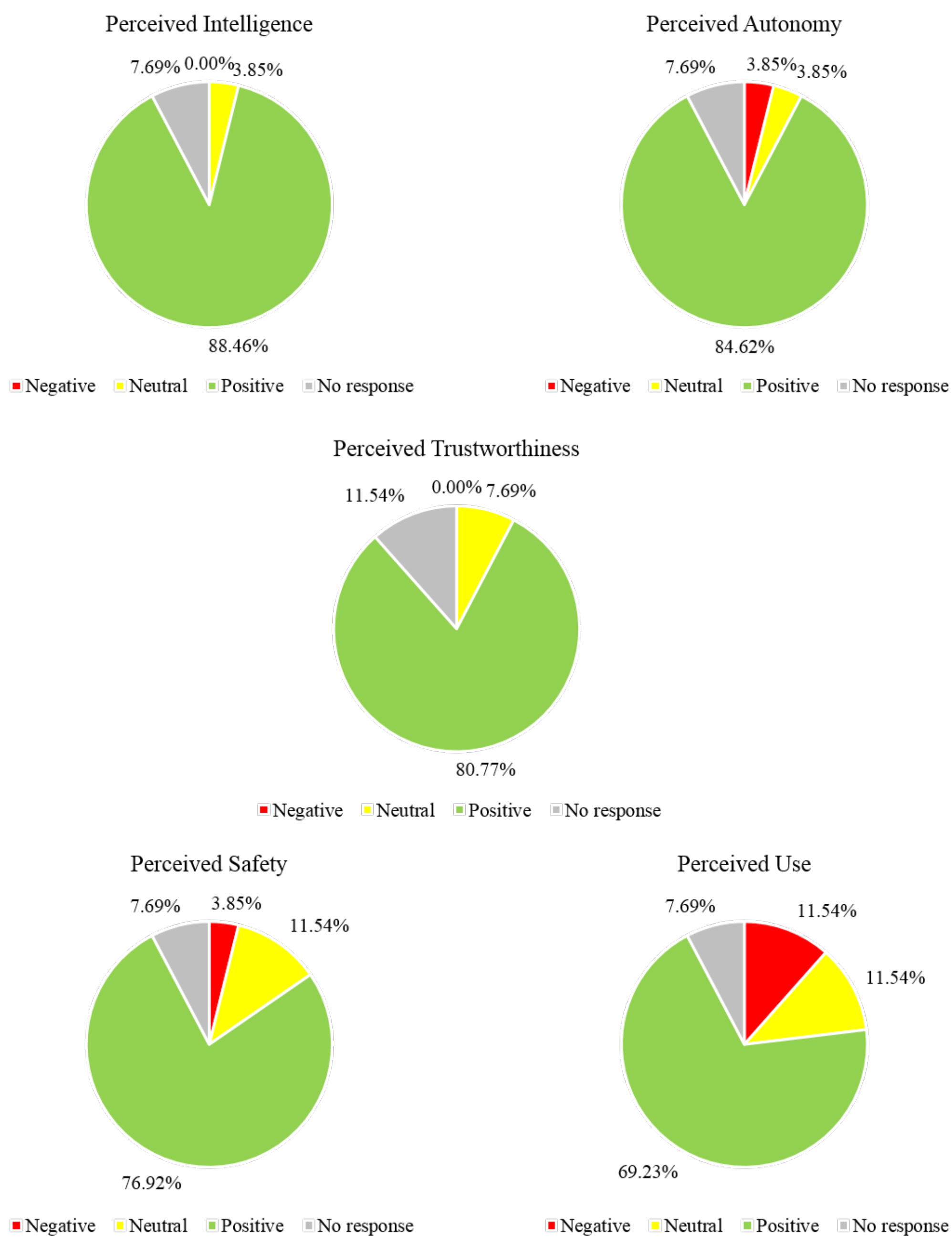

Fig. 8 Perceived trustworthiness ratings

5.1.1 Perceived Intelligence and Autonomy

The first 2 items looked at perceived vehicle intelligence and perceived level of autonomy. Overall, both items were perceived positively by both passengers and bystanders. The percentage of participants that rated positive agreement of the perceived intelligence of the vehicle was 88.46% (3 somewhat agree, 5 agree, and 15 strongly agree), while 84.62% of participants rated the perceived autonomy item positively (2 somewhat agree, 7 agree, and 13 strongly agree). Only one participant rated both items as neutral. This participant never rode or observed the vehicle operating autonomously. Later open-ended questions suggested that this participant also desired more feedback from the vehicle to quantify the vehicle's decision-making processes and autonomous capabilities. These findings suggest that individuals want to believe that the vehicle will be intelligent and have the capability to function without the direct control of an operator, even ones that have never seen the vehicle operate autonomously as seen in responses from Phase 1 operations. Results from Phase 2 operations suggest that individuals make determinations about the level of vehicle intelligence and autonomy even though the vehicle was not designed to have any directed feedback as to the specific intelligence architecture. This is important to the Army because it suggests perceptions about the driverless vehicle's ability are based on relatively few performance variables. Additionally, the Army spends more every year to run its installations than just about anything other than personnel costs. User and potential user perceptions are important to the acceptance of driverless vehicles. Automation can improve efficiencies and safe operations on bases and the degree to which it is widely adopted can have a positive impact on budgets and operational performance. Diving further into the factors that lead to these few perceptions of ability or competency of such vehicles can help developers focus on those elements most important to Soldiers in the field.

5.1.2 Perceived Trustworthiness

Self-report ratings of vehicle trustworthiness were positively rated such that 80.77% of respondents rated the perceived trustworthiness positively (2 somewhat agree, 8 agree, and 11 strongly agree). There were no negative ratings, and only 2 neutral ratings. Out of the 2 neutral ratings, one respondent had never ridden or observed the vehicle operating autonomously, and the second had previously ridden the vehicle 5–10 times during Phase 1 (operated by the human driver), but had seen it operate autonomously as an observer.

These overall positive findings could directly support the current design and functional capabilities of the vehicle for short duration travel, such that the current design features and capabilities provided adequate situation awareness needed to calibrate trust in the vehicle with minimal prior interaction. However, these positive trustworthiness ratings may also be influenced by the larger system including the human driver or safety operator onboard the vehicle, as well as command support and encouragement of ridership with the ARIBO driverless vehicle at WAMC. In addition, the 2 neutral responses suggest some individuals may need to physically see, experience, and understand the capabilities of the system before putting blind faith in the system.

5.1.3 Perceived Use

The perceived use question asked respondents if they felt the vehicle would be used regularly by the Soldiers at WTB, not just when operated by a driver or safety operator but also when the operator was removed from the vehicle. While there was slightly more divergence in responses, just under 70% of respondents rated the perceived use positively (6 somewhat agree, 5 agree, 7 strongly agree). These data suggest that to some degree Soldiers and civilians believe their fellows will value point-to-point, scheduled, and on-demand driverless transportation. However, there was some divergence in perceived amount of vehicle use: 2 strongly disagreed with this item, 1 disagreed, and 3 were neutral.

Respondents with these negative ratings for perceived use had limited to no prior interaction with the vehicle during Phase 1 or Phase 2 of operations and had some limited knowledge or understanding of how the vehicle could or would operate safely without a driver. This supports the need for increased access in the Army to autonomous vehicle technologies to increase understanding and trust to better support appropriate use of future robotic systems.

The 3 neutral ratings came from 2 people on their first ride and 1 who had ridden the vehicle more than 10 times. While some undirected feedback supported that these respondents would be willing to use the vehicle again, there was some hesitation on rating how others would use the vehicle. This was in part due to the limited knowledge of the larger population base regarding vehicle availability, limited hours of operation, and observations of vehicle runs without passengers. In addition, these data do not control for the presence of the safety operator, making it difficult to determine if respondents would recommend use of the vehicle with the safety operator behind the wheel although our data (Section 5.1.1) on trustworthiness suggests they would. Once the technology reliably and safely allows, future research should examine these questions without the presence of a safety operator.

5.1.4 Perceived Safety

Ratings for perceived safety were slightly higher with 76.92% rating perceived safety positively (3 somewhat agree, 6 agree, and 11 strongly agree). While it is possible that these ratings support the design and capabilities of the system to promote safety, it is also possible that some of these ratings were not based on interaction or observation of the vehicle but rather from the larger assumption that the Army would not allow vehicles on the road that were not safe. This supports the idea that trust in autonomy has larger implications than just improving engineering systems alone. This type of trust is related to the vehicle, but also the larger Army and support of the command. Future work would need to be conducted to address this more fully.

These 4 respondents had either neutral safety ratings (N = 3) or felt the vehicle was unsafe (N = 1). All these respondents had limited interactions with the autonomy features and capabilities of this vehicle. Therefore, it is possible to speculate that these evaluations may have been based on some bias or preconception of the technology, or influenced by the safety performance of the human driver. While additional research is needed to determine the specific reasoning behind these ratings, this finding supports the Army's need for increased access and exposure to robotic technologies. This is important to advancing shared situation awareness and understanding of future robotic capabilities to appropriately calibrate trust and promote effective use.

5.2 Acceptability of Vehicle Autonomy

Over the course of 3 years, the ARIBO vehicle has demonstrated the capability to effectively navigate through the medical complex; detect and avoid obstacles, other road users, and pedestrians; and follow traffic rules while operating in fully functioning driverless operations (with a safety operator present). However, actual system capabilities may not directly match perceived capabilities from passengers or bystanders with limited knowledge of the functional capabilities of the vehicle. Therefore, respondents assessed the perceived acceptability of the vehicle's autonomous navigation, obstacle detection and obstacle avoidance (ODOA), and the ability to follow traffic rules. While respondents may have never seen or personally interacted with the vehicle during autonomous operations, the results provide some insight into the user population's perceptions of future autonomy.

Respondents rated 3 capabilities: autonomous navigation, ODOA, and following road rules. Overall, 80.77% of the respondents found the autonomous vehicle navigation capabilities to be acceptable, while 73.08% found the ODOA and ability to follow road rules to be acceptable. Furthermore, there were no significant differences between respondents who had little to no interaction with the ARIBO vehicle and those who were passengers during driverless operations. This suggests that overall, individuals support the current and future capabilities of the vehicle.

However, there is still room to advance the engineering and design needed for increased understanding and support of these vehicle capabilities. The additional negative and neutral ratings on these 3 items provide some insight into the types of individuals and amount of information access that may be needed to increase acceptability ratings of these types of vehicle autonomy. For example, 3 individuals had neutral (N = 1) or slightly unacceptable (N = 2) ratings regarding the navigation-based autonomy. These respondents either had limited prior interaction with the vehicle or had concerns about the safety-based navigation and recommended more direct vehicle feedback for passengers. In addition, the acceptability ratings of the ODOA-based autonomy included 3 neutral ratings, a slightly unacceptable rating, and an unacceptable rating. Similarly, all these respondents had limited prior interactions with the autonomous capabilities of the vehicle. This finding suggests that perceived capabilities will be enhanced either through increased access to robotic systems through communication of capabilities or actual interaction. The acceptability of the vehicle to follow traffic rules ratings included 3 neutral and 1 slightly unacceptable rating. Most of these respondents had limited or no prior interaction with the vehicle, suggesting that similar to the above finding, increased communication of capabilities or interaction with the system can increase understanding of the capabilities. Further, a respondent was a prior passenger on the vehicle but had concerns of the safety of the vehicle following concerns related to right-of-way behaviors throughout an intersection. This suggests that there may be a benefit to share more information or feedback during an interaction to better communicate vehicle intent.

Overall, the data above indicate confidence in the vehicle's autonomy, navigation, and ability to detect and avoid obstacles. This suggests that autonomous vehicle performance capable of approximating human performance is what passengers and bystanders expect of autonomous vehicles. Further findings suggest that there may be a subset of people who have limited exposure to autonomy who would benefit from increased exposure and feedback of autonomous capabilities for navigation, ODOA, and the capability to follow road rules.

5.3 Recommendations for Vehicle Design

All respondents were given the opportunity to provide design feedback and recommendations related to rider comfort, pedestrian comfort, rider trust, and a future user display design.

5.3.1 Rider Comfort

All respondents were asked to provide open-ended recommendations for the future design of the vehicle to increase comfort of passengers onboard the vehicle. Out of the 26 respondents, only 6 provided directed comments for enhancing passenger comfort. The remaining 20 respondents left this item blank, specifically denoted that they had no direct feedback, or stated the vehicle provided adequate passenger comfort for the short duration of the trip. Table 1 lists the specific feedback and comments.

Table 1 Passenger comfort feedback and vehicle design guidelines

Number of comments	Specific feedback
2	Second row has limited leg room for tall passengers or those with severe injuries
1	Seats are uncomfortable, especially for those with injuries
1	Need seat belts[a]
2	Need feedback from vehicle or signage to communicate vehicle capabilities when interacting with other road users in intersections, parking lots, and on roadway

[a] All seats were instrumented with seatbelts. Recommendation came from person who never rode in the vehicle.

Two major types of feedback included design recommendations for physical comfort and for providing passenger safety. The first was directed at accommodations for this specific use population, including more comfortable seats and extended leg room. This accommodation was considered in the mobile application when scheduling a ride; a wheelchair-accessible vehicle with extended leg room was available for transport and could be selected at the time of reservation. The second design recommendation was specific to both physical safety and perceived safety. Seatbelts were already included for every seat on the vehicles. In addition, the need for communication to alleviate discomfort and mitigate uncertainty is paramount for increasing passenger comfort in the vehicle, especially when the safety operator is removed from the driver's seat. Future vehicle design considerations and research for driverless shuttles should address mechanisms to effectively communicate safety options available to passengers. Passenger comfort and safety features are clearly important to passengers and potential passengers of driverless transport vehicles. Features and tasks requiring action on the part of passengers (e.g., fasten seat belts) should be clear from early in the reservation process to embarkation through transport and debarkation.

5.3.2 Pedestrian Comfort

Since these vehicles operate on both roadways and sidewalks, all respondents were asked to provide open-ended recommendations for the future design of the vehicle to increase comfort of pedestrians near the vehicle. Out of the 26 respondents, 8 respondents provided feedback related to pedestrian comfort. The remaining 18 respondents left this item blank, specifically denoted that they had no direct feedback, or felt the vehicle had no direct effect on pedestrians. Table 2 provides specific feedback and comments.

Table 2 Design guidelines for pedestrian comfort and safety

Number of comments	Specific feedback
4	Addition of audible alerts or warnings
1	Use of a flashing light so others can see the AIRBO coming[a]
1	Larger vehicle to increase pedestrian awareness
1	Inclusion of a large, legible sign onboard the vehicle stating that vehicle operates safely without a driver
1	Some type of warning is needed when approaching pedestrians

[a] Both vehicles were instrumented with a yellow safety light.

All design recommendations were specific to providing additional pedestrian safety. Specifically, the respondents were interested in providing pedestrians with awareness of the vehicle's presence and capabilities through means such as signage, or audible alerts or warnings. Some examples included a verbal acknowledgement of when the vehicle was paused for a pedestrian or a horn beep to let a pedestrian know the vehicle was waiting on them. Future research and vehicle design should examine common communication techniques used to communicate with able-bodied adult pedestrians, children, and pedestrians with disabilities (e.g., blind or deaf), as well as the implication of regional norms or variations in order to assess different types of alerts and warnings that could be used to effectively communicate vehicle intent with pedestrians.

5.3.3 Passenger Trust

All respondents were asked to provide recommendations for the design of the vehicle that would increase future rider trust in the vehicle, especially once the safety operator was removed from the driver's seat. Out of the 26 respondents, 5 provided design guidance on improving rider trust in the driverless vehicle. The remaining 21 respondents left the item blank, directly stated no guidelines, or specifically pointed out that current design did not lessen trust in the vehicle. All 5 of the comments were related to passenger awareness and ways to improve the passengers' perception of safety in terms of error prevention and mitigation, such as means for adapting control allocation. Table 3 provides specific feedback and comments.

Table 3 Design guidelines to increase passenger trust

Number of comments	Specific feedback
1	Change outward vehicle appearance (e.g., bright color) to increase nonuser awareness
1	Include eye-catching signage of features onboard the vehicle
1	A communication system with a human for emergencies
1	Include an emergency stop button that the passengers could press[a]
1	Capability to take control of the vehicle if unsafe

[a] Both vehicles were instrumented with multiple emergency stop buttons (see Fig. 6).

Development of appropriate vehicle autonomy and trust requires an understanding of how driverless vehicles and other road users will mutually interact during shared operations (Straub and Schaefer in press). The technology is not yet available for the general population to be familiar with autonomous vehicles. Access to these types of technologies will increase understanding and experience with the technology, which may lead to an increase in trust. It is difficult for people to trust something they do not understand or do not know about. Results from this open-ended feedback suggested that design guidelines should include both indirect and direct error prevention and mitigation strategies.

Specific form-based features can support (or hinder) expectations of vehicle capabilities (Groom and Nass 2007). For example, a feature such as changing the outward appearance of the vehicle to increase other road-user awareness indirectly mitigates issues that could occur when sharing the roadway, thus reducing the possibility of misunderstanding vehicle intent. Similarly, onboard signage of vehicle features or a communication system with person monitoring the system can increase the passenger's situation awareness of what the vehicle can and should be doing in certain situations.

Moreover, once the safety operator is removed from the driver's seat, there will be questions as to how passengers will be able to interact with vehicle and concern for how to respond in case of errors. At present, passengers have limited familiarity with the ARIBO vehicle and there is limited feedback onboard to communicate its state, intended behaviors, or awareness of the environment including pedestrian or vehicle awareness. This could directly impact passenger's comfort and trust and directly impact the need to take control of the vehicle in what could be perceived to be a harmful situation. An example of a harmful situation was when the autonomous vehicle was in an intersection and another vehicle was approaching, there was no indicating that the other vehicle was sensed. Therefore, specific design recommendations for direct error mitigation included the capabilities to take over control either through use of emergency stop buttons or full manual controls. This leads to a larger issue of not just having these design features available, but appropriate use of these features and responsibility. Appropriate control allocation can only be established when the riders and vehicle have developed a shared situation awareness (Schaefer et al. 2016). This leads directly into the benefits of the inclusion of a mobile application or user display to communicate vehicle intent to the passenger and adequate warnings in situations that may require human intervention.

5.3.4 Mobile Application or User Display Design

All respondents were asked if a cell phone application or onboard user display would be beneficial to provide vehicle information to riders. Out of the 26 respondents, 16 said yes, 6 said no, and 4 did not respond. In addition, 7 respondents provided suggestions for the design guidelines relating to navigation-specific feedback, error reporting, and contact information. These suggestions and comments ranged from simple things such as posting hours of operation and contact information, to having the vehicle provide specific route information and verification. Table 4 provides specific feedback and comments that could be applied to either a cell phone application or onboard user display.

Table 4 Design guidelines for a user display

Number of comments	Specific feedback
4	**Navigation-specific feedback** • Estimated time of arrival • Notification of change in vehicle behaviors (e.g., preparation to stop, turning, destination arrival) • Easy to read route (e.g., stop locations; similar to GPS navigation system) • Length of time until the vehicle arrives at the pickup location
3	**Error reporting** • Interactive display for reporting issues, errors, and rider concerns • Denote number of accidents to date or days without errors • Provide safety-related information and comments
1	**Contact information** • Provide contact information (e.g., phone numbers and hours of operation)

Interestingly, top design considerations to advance passenger trust in the vehicle had less to do with vehicle autonomy than they did with vehicle functional performance. In other words, being notified of information such as estimated time of arrival and route information is similar to information one might either ask a human driver or be expected to have available in a vehicle driven by a human. Even a relatively simple suggestion such as posting contact information speaks to trust development in the autonomous system. It suggests passengers want a human fallback option to call in case of error or if they become confused and need some aspect of the system explained to them, especially if an error is reported and the passenger has no idea what to do next. Teasing out the reasons behind this apparent desire for human contact is an area of future research. Additionally, it will be important to understand the point at which trust in the system supplants this need.

6. General Discussion

When a passenger gets into a vehicle driven by a human, it is easy for them to put themselves in the driver's place. This is a familiar interaction for most passengers, and therefore one that contributes to their perceptions of safety as a passenger. It is assumed that the driver is using sight, sound, and experience to pay the right amount of attention to the road and behaving appropriately. Similarly, when a driver transitions into a role of a safety operator, it is also assumed that there is an extra level of safety in place since the operator is ultimately responsible for the passengers and bystanders. When the vehicle is controlling itself, there is no similar connection. Passengers have only their general preconceptions of autonomous systems to assess the appropriateness of decisions. At best, the average passenger has only a limited understanding of the sensor systems the vehicle is using to perceive and understand its environment, until they have ample opportunity to interact with the system. Most of the questionnaire responses in our study point to the fact that observation and interaction with autonomous vehicles can increase feelings of trustworthiness and perceived understanding of the actual autonomous capabilities of the vehicle. However, for those with a limited understanding of the autonomy, there is a need to move beyond just advancing the engineering capabilities. To facilitate interaction and an efficient transportation system, passengers and bystanders need to appropriately trust in automated driverless vehicle's ability to operate safely and abide by norms and generally accepted rules of the road. To do this they need to be able to understand how the vehicle operates or how to gather information about its operation from before or during interaction. In addition, open-ended feedback from respondents suggests the need for a human-in-the-loop, especially when the safety operator is removed from the vehicle.

The general public, represented in this study by a random sample of Soldiers and civilians in and around the WTB complex, has very little direct experience with autonomous technologies. Expectations and perceptions after direct experience affected preconceptions in a generally positive way. Vehicle design should include intuitive, universal interfaces focused on providing information passengers and pedestrians could use to make a connection to the vehicle. This connection and demonstrated reliability will improve trust and overall performance in mixed traffic environments.

6.1 Key Findings

There were 7 key findings from this work.

1) Most people had positive trust-related ratings despite whether or not they have had previous direct interaction with the vehicle's autonomy.

2) People believed that the autonomous capabilities of the ARIBO were acceptable or would be in the future, regardless of whether or not they had seen the vehicle operate autonomously or not.

3) The small group of individuals with lower perceptions of trustworthiness and acceptability were found to have a minimal understanding the system, suggesting that more detail or information prior to or during the ride could increase feelings of safety and security.

4) Recommended design features to improve passenger comfort were specific to the potential needs of the wounded Soldier population who may use this vehicle and the general safety of all riders. These included more comfortable seats, extended leg room, safety belts, and effective communication of safety features and options to all passengers.

5) Recommended design features to increase pedestrian comfort were specific to pedestrian safety awareness. While the current vehicle capabilities only had the vehicle slow down, or stop and wait for pedestrians, feedback suggests that additional alerts or warnings (e.g., verbal acknowledgment when vehicle is paused for pedestrian, horn sounding to let pedestrian know the vehicle is waiting, or signage explaining that this is a driverless vehicle) would improve vehicle–pedestrian interaction.

6) Recommended design features to increase passenger trust in the vehicle were specific to perceptions of safety, specifically error prevention and mitigation. Specific features, such as vehicle size, coloration, or signage, can communicate to other road users that the vehicle is a driverless vehicle,

thus impacting vehicle-to-vehicle interaction. In addition, it is essential to identify methods for determining when and how a passenger can adapt control allocation and respond to high-risk situations once the operator is removed from the vehicle.

7) The system would benefit from a user display (e.g., mobile application or onboard display) to communicate vehicle awareness and actions, including but not limited to navigation-specific feedback (e.g., estimated time of arrival, changes in behaviors, routes, arrival time), error reporting (e.g., means to report issues or errors, number of errors or accidents, safety-related information), and a means to connect to a human monitor.

6.2 Limitations

There were 2 potential limitations to this work.

1) Limited Ridership: Despite the fact that WTB averages more than 700 appointments at WAMC each week and that the barracks are capable of housing more than 600 Soldiers at a given time, there was limited response from the WTB Soldiers. This was in part impacted by a limited number of scheduled riders using the ARIBO Mobile application, including 12 scheduled riders with 112 rides during Phase 1 of operation and 5 scheduled riders with a total of 15 rides during Phase 2 of operation. In addition to the above riders, unscheduled riders and Soldiers who responded to email requests for feedback made up most of the respondents. However, specifics as to the amount of total riders and rides were not recorded. These limitations in sample size limited the type of statistical analysis that could be conducted and directly influenced the potential outcomes of this work.

2) Trust: Subjective assessment of trust in an autonomous vehicle is not restricted to the engineering technologies of the vehicle alone. Trust is assessed with respect to a whole system. For the ARIBO vehicle this system included a driver or safety operator, the users or potential users at the WTB complex, and the direct support of the command staff for vehicle integration and use. Therefore, it is possible that the respondents assumed that the larger Army would not allow a technology that was not safe or function appropriately to be used by the WTB Soldiers. Therefore, based on the current questionnaire design, it is not possible to vet the trust-related responses without additional follow-up research.

7. Conclusions

Although this user perception study had far less participation than anticipated, a number of areas for future research were highlighted that are relevant to robotic vehicle deployment in the Army. In general, individuals have limited or no experience with robotic technologies, such as driverless vehicles, but minimal exposure to these technologies can positively impact trust ratings, as found in the study. This finding could be specific to the vehicle capabilities and design for the use of personnel transport, but could also be influenced by the larger operations space. For example, trust in the vehicle could be directly influenced by direct access to the driver or safety operator. How this trust changes when a safety operator is removed from the vehicle is a future line of research. These findings may have also been influenced by reputation of the larger Army such that individuals may feel that the Army would not allow nor encourage ridership if the design and equipment were not safe—this is a thought that will have to be tested with data collected in the future.

While the ARIBO shuttle vehicles were rated positively across the trust and acceptability questions, specific design guidelines were provided to improve trust and comfort by passengers, pedestrians, and other road users. Most of the feedback supported the need for increased communication either prior to use or during operations. Increased communication for passengers and pedestrians would include education on the vehicles technology and capabilities. Increased communication for vehicle-to-vehicle interactions would include ways of letting other vehicles know that the vehicle had detected the other vehicle and its plan of action. Overall, these findings support the advancement of robotic technology and start to show that such technology may provide major advantages for the Army in the area of manned–unmanned teaming.

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Appendix A. Previous Simulation Study Findings

Previous findings recommended 4 areas of design recommendations to increase situation awareness to engender trust in the Applied Robotics for Installations and Base Operation (ARIBO) vehicle.[1]

1. **External Environmental Awareness: Passenger wants to know that the vehicle knows what is going on in the environment**
    - 13 out of 20 participants provided 14 design recommendations
    - Examples include obstacle detection indicators on an onboard user display, response time indicator for vehicle behavior, and visual/auditory pedestrian safety warnings and alerts.

2. **Navigation-based Autonomy: Passenger wants to know where the vehicle is currently located and where it is going**
    - 15 out of 20 participants provided 26 recommendations
    - Examples include: pickup and drop-off locations on an onboard or mobile display, estimated time of arrival indicator, and visual indicators such as turn signals to communicate changes in vehicle direction

3. **System Awareness: Passenger wants to know that the vehicle is aware of its current state**
    - 9 out of 20 participants provided 11 recommendations
    - Examples include activation lights, speed indicator, display that shows changes in vehicle behaviors, vehicle health status such as fuel or battery life, and countdown until a specific vehicle action

4. **Passenger Awareness and Safety: Passenger wants to make sure the vehicle is aware of those onboard**
    - 6 participants provided 7 recommendations
    - Examples include auditory or visual safe boarding or exiting alerts, notice of engagement of safety features, weather indicators

[1] Schaefer KE, Brewer R, Putney J, Mottern E, Barghout J, Straub ER. Relinquishing manual control: collaboration requires the capability to understand robot intent. Proceedings of the 9th International Workshop on Collaborative Robotics and Human Robot Interaction; 2016 Oct 31–Nov 4; Orlando, FL. 2016. Los Alamitos (CA): IEEE Computer Society; c2016. p. 359–366.

Appendix B. Questionnaires

This appendix appears in its original form, without editorial change.

ARIBO Driverless Vehicle: Phase 1 Questionnaire

1. Circle the most appropriate description of your interaction with the vehicle:

   Driver **Passenger** **Observer (not riding on vehicle)**

2. How many times have you been a passenger on this vehicle? ________________

3. Is this your first time filling out this questionnaire (circle one)?

   Yes **No**

4. Have you seen the vehicle operate autonomously without a driver controlling it (circle one)?

   Yes **No**

Directions: Please rate your agreement with each item based on your beliefs about the FUTURE capabilities with the vehicle.

5. The vehicle will be intelligent (circle one)

Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree

6. The vehicle will control itself (circle one)

Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree

7. The vehicle will be used regularly by Soldiers at Ft. Bragg (circle one)

Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree

8. The vehicle will be safe (circle one)

Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree

9. The vehicle will be trustworthy (circle one)

Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree

Directions: Please rate acceptability of each item based on your beliefs about the FUTURE capabilities of the vehicle.

10. The vehicle will be able to navigate throughout the medical facilities without human intervention.

Totally Unacceptable	Unacceptable	Slightly Unacceptable	Neutral	Slightly Acceptable	Acceptable	Perfectly Acceptable

11. The vehicle will be able to avoid other vehicles, obstacles, and pedestrians without human intervention.

Totally Unacceptable	Unacceptable	Slightly Unacceptable	Neutral	Slightly Acceptable	Acceptable	Perfectly Acceptable

12. The vehicle will be able to respond to traffic rules (e.g., road signs, road rules) without human intervention.

Totally Unacceptable	Unacceptable	Slightly Unacceptable	Neutral	Slightly Acceptable	Acceptable	Perfectly Acceptable

Directions: The following questions are open-ended questions that will allow you provide recommendations specific to the future design of the vehicle.

13. Please provide any recommendations for the design of the vehicle in order to increase the comfort of a **passenger** onboard.

14. Please provide any recommendations for the design of the vehicle in order to increase the comfort of **nearby pedestrians**.

15. Please provide any recommendations for the design of the vehicle that would **increase trust** in the vehicle.

16. Should we provide passengers with a cell phone app or onboard display that provides vehicle information (circle one)?

Yes **No**

ARIBO Driverless Vehicle: Phase 2 Questionnaire

1. Circle the most appropriate description of your interaction with the vehicle:

   Safety Operator **Passenger Observer (not riding on vehicle)** **Other**

2. How many times have you been a passenger on this vehicle? ________________

3. Is this your first time filling out this questionnaire (circle one)?

   Yes **No**

4. Have you seen the vehicle operate autonomously without a driver controlling it (circle one)?

   Yes **No**

Directions: Please rate your agreement with each item based on your PAST/CURRENT experiences with the vehicle.

5. The vehicle is intelligent (circle one)

Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree

6. The vehicle controls itself (circle one)

Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree

7. The vehicle will be used regularly by Soldiers at Ft. Bragg (circle one)

Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree

8. The vehicle is safe (circle one)

Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree

9. The vehicle is trustworthy (circle one)

Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree

Directions: Please rate acceptability of each item based on your PAST/CURRENT experiences with the vehicle.

10. The vehicle navigates throughout the medical facilities without human intervention.

Totally Unacceptable	Unacceptable	Slightly Unacceptable	Neutral	Slightly Acceptable	Acceptable	Perfectly Acceptable

11. The vehicle avoids other vehicles, obstacles, and pedestrians without human intervention.

Totally Unacceptable	Unacceptable	Slightly Unacceptable	Neutral	Slightly Acceptable	Acceptable	Perfectly Acceptable

12. The vehicle responds to traffic rules (e.g., road signs, road rules) without human intervention.

Totally Unacceptable	Unacceptable	Slightly Unacceptable	Neutral	Slightly Acceptable	Acceptable	Perfectly Acceptable

Directions: The following questions are open-ended questions that will allow you provide recommendations specific to the future design of the vehicle.

13. Please provide any recommendations for the design of the vehicle in order to increase the comfort of a **passenger** onboard.

14. Please provide any recommendations for the design of the vehicle in order to increase the comfort of **nearby pedestrians**.

15. Please provide any recommendations for the design of the vehicle that would **increase trust** in the vehicle.

16. Should we provide passengers with a cell phone app or onboard display that provides vehicle information (circle one)?

    Yes **No**

    If so, what type of information should be provided to help increase a passenger's trust in the vehicle?

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List of Symbols, Abbreviations, and Acronyms

ARIBO	Applied Robotics for Installations and Base Operations
GPS	global positioning system
ODOA	obstacle detection and obstacle avoidance
TARDEC	US Army Tank Automotive Research, Development and Engineering Center
WAMC	Womack Army Medical Center
WTB	Warrior Transition Battalion

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MCXC WTB CO
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